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Studies on Thermal Contraction of Crankshaft Bearings under Extreme Low Temperatures

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This paper presents how the contractions of the main components of a V6 motor with low engine displacement are determined for the cold-start phase under extreme low temperature. Internal combustion engine components have complex geometries and to obtain the thermal contractions, in the research, used the method of finite element analysis. The phenomena of thermal contractions are studied for the cold-start situations at extreme low temperature, knowing that the cold-start phase of an internal combustion engine is the main factor that determines moving rotational and translational parts wear life. Checking the proper choice of clearance is particularly important, as the use of inappropriate values of it leads to rapid operation destruction of the engine group components. The results obtained for the thermal clearances of crankshaft bearings are mathematically modeled and the relations can be used for calculating the clearances. The mathematical models are also useful for implementing in different software tools.

Keywords: Engine, Engine block, Crankshaft bearings, Thermal contraction, FEA

Introduction

In the design and manufacturing of the internal combustion engines the current main direction is to make engines group cubic capacity reduced and very high power liters. This trend is imposed by the requirements to minimize the ambient pollution and fuel consumption. Modern engines achieve high power liters in a small volume of the engine using supercharging technologies and advanced digital control of combustion.

Engine production is dominated by computer systems used in design and management of manufacturing activities, including commercial software systems like: Unigraphics, Pro Engineer, SolidWorks, CATIA, ANSYS, AutoCAD, ALIAS and software tools developed for specific applications [1].

It is well known that in the design and modern manufacturing the most powerful tool for making calculations and simulations is Finite Element Analysis (F.E.A) method. Entity based on finite element analysis is the finite element. It has some basic properties: geometric shape, number of nodes, degree polynomial interpolation and the type of analysis [2].

For simulation of thermal expansion of 3D models with complex shapes macromolecular finite elements are used, thus the engineers get exactly thermally loaded body shape deformation values [3].

Thermal expansion phenomena of complex bodies cause deformations in the material structure of the mechanical assembly parts, they are successfully analyzed using software packages such as: ABAQUS (included in the application package Simulia – developed by Dassault Systems), ANSYS – Structural Simulation and CATIA (Analysis & Simulation).

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For comparison between the finite element analysis results and real physical phenomena in thermal expansion and contraction of the engine block, it can use the measurement method without physical contact DIC (Digital Image Correlation), this method allows the measurement of parts in a very large temperature field [4].

This paper presents some researches dedicated to the phenomena of contraction modeling of the crankshaft bearing sections for an internal combustion engine during the cold start phase under extreme low temperature conditions, specific the cold climates geographical areas, for the static phase, time period: 1–5 seconds. This is the phase that generates the maximum wears of mechanical engine components. The studies of the behavior areas of joint crankshaft with engine block is extremely important because in this way it is assured a long engine running in good conditions.

Materials and Methods

Working method used for determination of the geometry changing of the crankshaft slots area consists of engine block and crankshaft 3D modeling using the tools provided by CATIA V5: Workbench Sketcher, Part Design, Assembly Design, Digital Mockup and F.E.A. and simulation developed in ANSYS 15.0 environment.

The main technical characteristics of the engine group studied in terms of contraction phenomena are presented in Table 1. This engine is low displacement type with high liter power.

Table 1 Main technical characteristics of engine group.

Engine:	Spark ignition type
Rated speed:	8000 [mn^{-1}]
Engine displacement:	1200 [cm^3]
Number of cylinders:	6
Cylinder position:	Normal – V at 120°
Bore:	70 [mm]
Stroke:	48.7 [mm]
Timing system:	D.O.H.C.
Engine Power:	200 [HP]

This engine group is used in the construction of cars, S.U.V. (Sport Utility Vehicle), ATV (All – Terrain Vehicle) high power, snowmobiles, electricity generating units and stationary pumps. In Fig. 1 the V6 engine block and crankshaft digital prototypes in an assembly mode is shown and in Fig. 2 the visualization is done with a 0.6 scroll coefficient.

The materials used for the studied parts are the following: lightweight aluminum for engine block and oil pan, and steel alloys for crankshaft and screws.

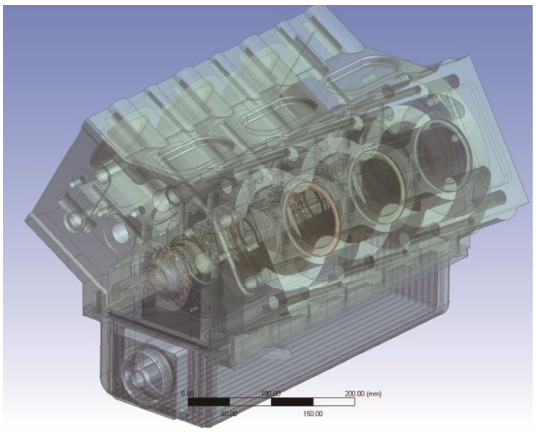

Fig. 1 Assembly - engine block and crankshaft (ANSYS fault detection).

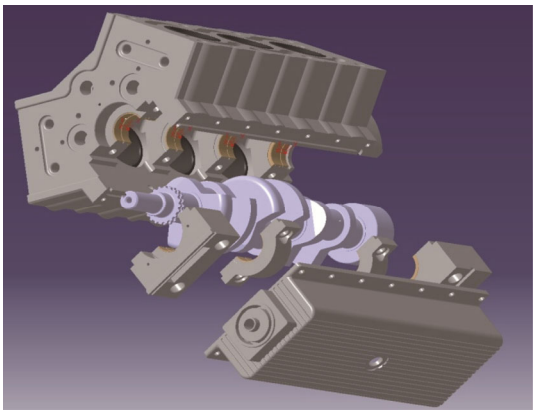

Fig. 2 Assembly - engine block and crankshaft (Scroll Explode = 0.60) CATIA V5.

In this studies on contraction phenomena in the components of the engine block under the extreme low temperatures the following coefficients of thermal expansion [5] were used: Mild steel = 15 [K-1×10^{-6}], Aluminum = 23 [K-1×10^{-6}] and Cooper = 17 [K-1×10^{-6}].

For the construction of the engine group a lightweight constructive solution was used for assembling an engine block, made of light alloys based on aluminum, with cylinder liners made of gray cast iron alloys.

Manufacturing of light alloy engine block and its assembly with cylinder liner, materials with high resistance to mechanical stress is widespread in engines domain and general purpose multi cylinder (engines for cars, motorcycles, stationary power generating units of electricity or pumps) engine. Because the engines are designed for minimum pollution, in the manufacturing, it is necessary to use processes in accordance with environmentally friendly machining principle with no lubrication or with a minimum volume of lubrication [6]. To achieve digital prototype for the assembly, the modeling work was divided into two parts: modeling of individual components and their assembling into a single model with assembly

constraints from CATIA V5 Assembly Design module (coincidence condition, surface contact, off-set, angular displacement) [7]. Assembling constraints are a very important element in the modeling activity because of these constraints is applied physical connections for components which will be simulated with the F.E.A. tool from ANSYS software system. These connections are automatically changed in contacts and they are made available to the user in toolbar ANSYS Multiphysics - Connections-Contacts. In this work were used connections type *No Separation*, *Bonded* and *Frictional* [8].

In Fig. 3, the positions of User Axis System for every crankshaft bearings, and the surfaces (Bearing Hole 1-4) for which the thermal deformation analysis was performed is presented in details.

Fig. 4 shows the crankshaft and the contact area positions of the motor sleeve bearings. They are numbered starting with the distribution. In this figure it is easy to identify the inner channel positions in the oil guide. These channels have a nonlinear behavior of the crankshaft to thermal requests. Thermal deformations caused by very low temperature engine starting at low sliding crankshaft bearings, in the engine block slots, can cause rapid wear or failure of internal combustion engine.

Table 2 presents the main defects which affect the proper working of the engine, sharp reduction of service life of the engine and also increases its operating costs.

To avoid these harmful phenomena, proper working of the engine is required to accurately simulate these phenomena of thermal deformation and to verify the accuracy of the geometrical parameters of the design and manufacturing. To calculate the thermal strains, clearance in sleeve bearings and tightening the mounting, because of complex geometric shapes engine block and crankshaft, is necessary to use several methods of calculation, for each specific geometric shape, outlined in Table 3.

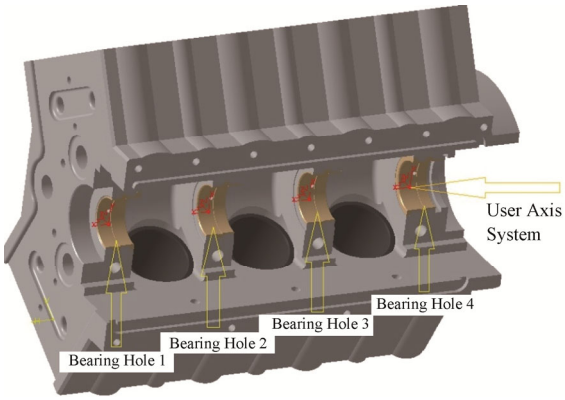

Fig. 3 Engine block - User axis system and position details - CATIA V5.

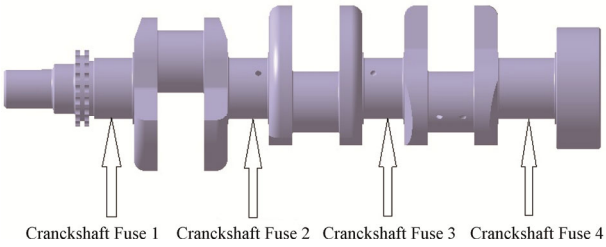

Fig. 4 Crankshaft - right side position - CATIA V5.

Results and Discussion

For extracting numerical data on the spatial position of the crankshaft changes, its clamps in the engine block was generated finite element analysis using ANSYS software system, with the following values for the main operating parameters:

- finite element type: linear;
- clamps necessary for cancellation of the degrees of freedom of assembly (DOF);

Table 2 Main defects affecting proper working of engine.

Condition of engine block assembly – crankshaft	Description dangerous physical phenomenon	Main defects that affect engine operation	Operating costs
Cold start phase motor: t = -32 – 0 [°C]	*Dangerous canceling the clearance from bearing:* relative rotational motion tightening metal / metal	Immediate destruction of sliding bearing and crankshaft fuse	40% of the total cost of the engine
	Dangerous reducing clearance in the camp leading to the expulsion of the oil film: relative rotation motion of the contact type metal / metal	Rapid destruction of the sliding bearing and crankshaft fuse	40% of the total cost of the engine
Transient engine operation: t = 10 – 50 [°C]	*Clearance of the bearing is too low, the oil film does not ensure proper lubrication of the contact area:* moves relative to the type of contact metal / metal crankshaft bearings	Sharp reduction of service life of the engine / increase maintenance costs	10% increase maintenance costs
Hot engine operation: t = 60 – 105 [°C]	*Dangerous growth of the clearance in the bearing leading to the expulsion of oil pressure loss of lubrication circuit:* moves relative to the type of contact metal / metal in the vast majority of engine components	Sharp reduction of service life of the engine / increase maintenance costs	15% increase maintenance costs

Table 3 Method of calculating and formulas

Formula / method of calculating	Explanation of terms	Area of application

$t = t_0 + \frac{S_{max} + j}{\alpha \cdot d} \times 10^{-3}$ (1)
Units: [℃]
	t = heating temperature;
	t_0= environment temperature (20℃);
	S_{max}= maximum of negative allowance;
	j = clearance for insertion;
	α = coefficient of linear thermal expansion;
	d = common diameter.
		Calculation of thermal expansion cylinder liner, it is suitable for parts with simple geometry, cylindrical sleeve type [9].

$D_t = \min\left[\left(\sqrt{(X_1 + C_1)^2 + (Y_1 + C_2)^2} - r\right) \cdot 2\right]$ (2) Units: [mm]	X, Y = base point displacement vector (the application point coordinates X, Y and the circular area corresponding height Z); C1, C2 = the values of the displacement vector projection after the coordinate axes (C1, C2 on the X, Y axis); r = common radius.	Calculation of thermal expansion slots in the body of the cylinder block assembly (for bodies with complex geometries) using F.E.A. method (Finite Element Analysis) displacement vectors for extracting projections [10].
$j_C = j + 2 \times (D_{VFmax} - D_{VHmax})$ (3) $j_H = j + 2 \times (D_{VHmax} - D_{VFmax})$ (4) Units: [mm]	J_C = clearance (cold engine situation) J_H = clearance (hot engine situation); D_{VFmax} = maximum of displacement vector for crankshaft fuse; D_{VHmax} = maximum of displacement vector for engine block hole.	Calculation of the differences in crankshaft bearings using F.E.A. method (Finite Element Analysis) to extract maximum displacement vectors.

- heating temperature: value of all the bodies studied (Loads − Thermal condition);
- ambient temperature: 20 Celsius degrees.

The main part of the motor group, the engine block, was immobilized in the process of finite element analysis respecting actual attachment areas in the auto vehicle body. For this purpose were used the contact surfaces of the engine block with the clutch case and the frontal support bracket of the engine. In Fig. 5 the section through crankshaft liner neck (crankshaft fuse) zone deformed at -32℃ temperature condition is shown.

After performing the finite element analysis, in the tree structure from the user request tools: solution tool (total deformation and directional deformation), resultant tools, structural error and equivalent stress are inserted.

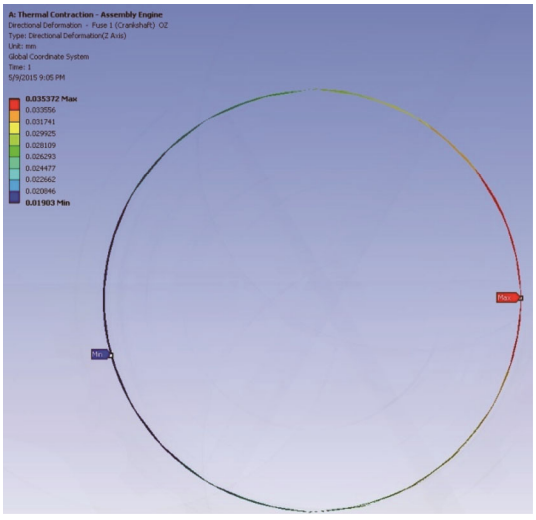

Fig. 5 Crankshaft section contraction at -32℃ - ANSYS results.

Fig. 6 presents the results of thermal deformations on the engine block in the cold start phase The movement of the rigid body to strain ties in XOZ plane is visible, and this strain's movement is determined by symmetrical position to the plane of the fixing points with auto vehicle body and clutch case/gearbox. The maximum deformation are located in distribution zone, because in this area are positioned the engine clamps that allow translational movements along OX axis. The engine rear zone (clutch zone) is rigid fixed with gearbox housing, without OX, OY, OZ translational movements.

The table of values extracted after the complete analysis, is shown in Fig. 7. It can be seen that different behavior of thermal deformations in all the four bearings of the crankshaft, this behavior is confirmed by the phenomenon of unequally wears of the crankshaft liners neck.

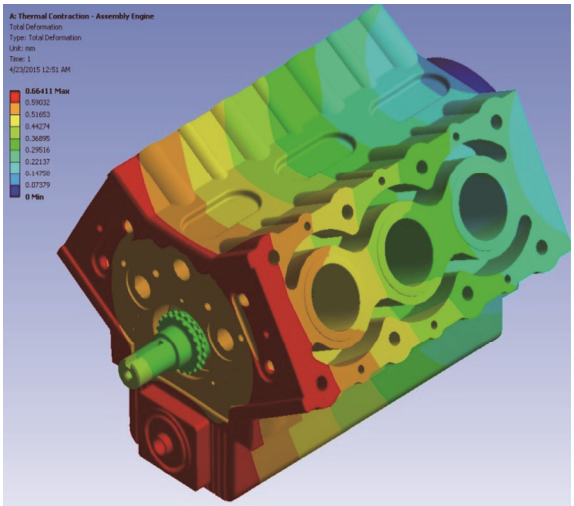

Fig. 6 Contracted assembly (-32℃) - ANSYS results.

Assembly Engine - Thermal Contraction and Thermal Clearance

t [°C]	Cranckshaft				Bearings				Thermal Clearance			
	Th_contr_Fuse1 [mm]	Th_contr_Fuse2 [mm]	Th_contr_Fuse3 [mm]	Th_contr_Fuse4 [mm]	Th_contr_Bearing1 [mm]	Th_contr_Bearing2 [mm]	Th_contr_Bearing3 [mm]	Th_contr_Bearing4 [mm]	ThC_Bearing1 [mm]	ThC_Bearing2 [mm]	ThC_Bearing3 [mm]	ThC_Bearing4 [mm]
-32 °C	0.04	0.04	0.038	0.05	0.079	0.068	0.065	0.058	0.021	0.032	0.033	0.052
-30 °C	0.039	0.038	0.037	0.048	0.076	0.065	0.059	0.055	0.023	0.033	0.038	0.053
-25 °C	0.035	0.034	0.034	0.044	0.069	0.055	0.053	0.05	0.026	0.039	0.041	0.054
-20 °C	0.031	0.031	0.03	0.039	0.062	0.051	0.048	0.044	0.029	0.04	0.042	0.055
-15 °C	0.027	0.027	0.026	0.034	0.054	0.046	0.042	0.038	0.033	0.041	0.044	0.056
-10 °C	0.024	0.021	0.023	0.03	0.047	0.039	0.036	0.033	0.037	0.042	0.047	0.057
-5 °C	0.02	0.02	0.019	0.028	0.04	0.036	0.031	0.03	0.04	0.044	0.048	0.058
0 °C	0.016	0.016	0.015	0.018	0.032	0.028	0.025	0.019	0.044	0.048	0.05	0.059

Fig. 7 Values of thermal contraction and thermal clearance in crankshaft bearings.

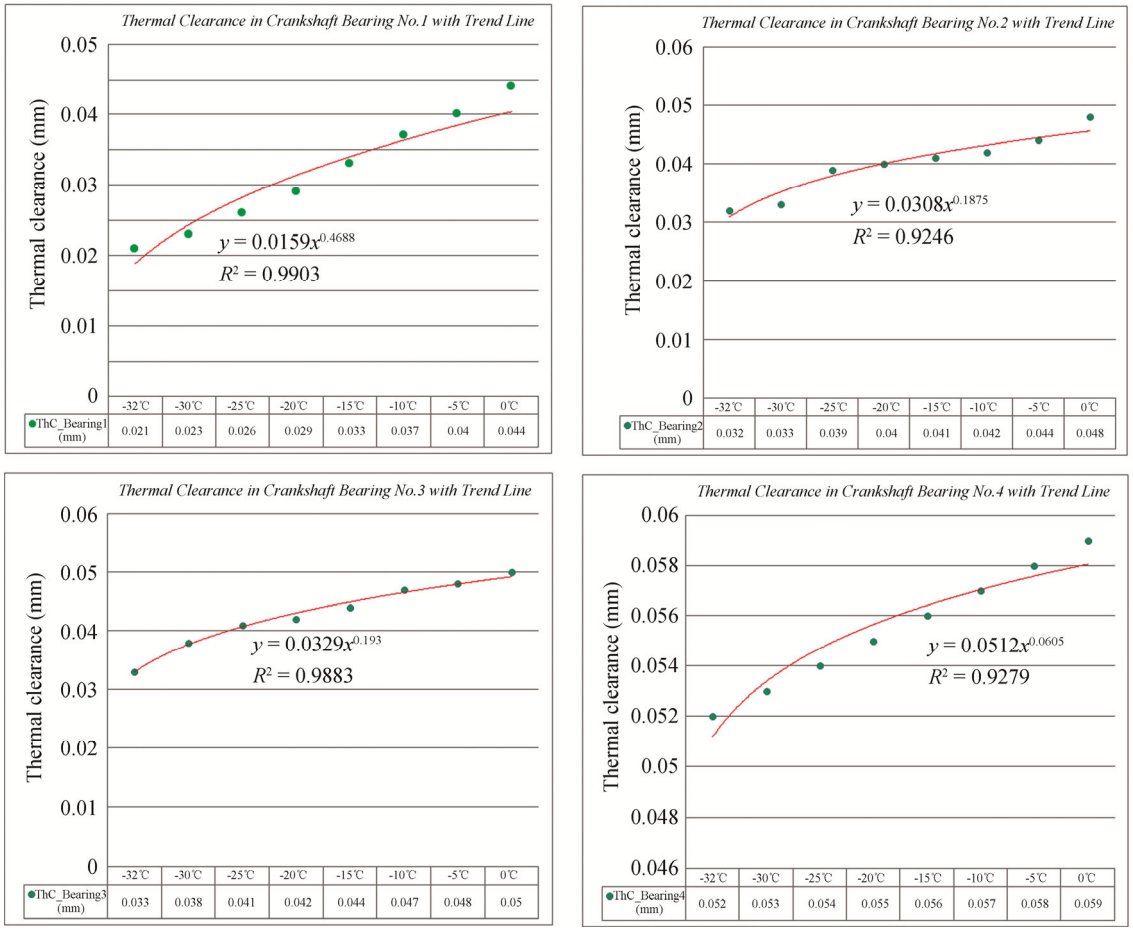
Thermal Clearance in Crankshaft Bearing No.1 with Trend Line
Thermal clearance (mm)
y = 0.0159x^0.4688
R² = 0.9903
ThC_Bearing1 (mm)
Thermal Clearance in Crankshaft Bearing No.2 with Trend Line
Thermal clearance (mm)
y = 0.0308x^0.1875
R² = 0.9246
ThC_Bearing2 (mm)
Thermal Clearance in Crankshaft Bearing No.3 with Trend Line
Thermal clearance (mm)
y = 0.0329x^0.193
R² = 0.9883
ThC_Bearing3 (mm)
Thermal Clearance in Crankshaft Bearing No.4 with Trend Line
Thermal clearance (mm)
y = 0.0512x^0.0605
R² = 0.9279
ThC_Bearing4 (mm)
-32°C -30°C -25°C -20°C -15°C -10°C -5°C 0°C

Fig. 8 Modeled data for thermal clearances in crankshaft bearings

In the crankshaft model for finite element analysis, DOF (Degree of Freedom) cancellation was performed using its fixation in the area of fly wheel flange (clutch zone) and by four constrains type of surface slider, applied over exterior surfaces of the four linear fuses. These constrains behave similarly with real supports of the crankshaft in engine block bearings.

The data were analyzed and for thermal clearance the following mathematical models were obtained:

bearing 1

$$y = 0.0159x^{0.468} \tag{5}$$

bearing 2

$$y = 0.0308x^{0.187} \quad (6)$$

bearing 3

$$y = 0.0329x^{0.193} \quad (7)$$

bearing 4

$$y = 0.0512x^{0.060} \quad (8)$$

These mathematical models can be used in practice for calculating the deformations and for implementing in specific software tools.

Fig. 8 shows the graphical results from the finite element simulation of behavior of the parts to the thermal requests, its points of change of its allure after minus 30° C are determined by the fact that after this temperature the interval between two iterations has been increased from 2℃ to 5℃. In this way the time for analysis was reduced without affecting allure trend line. It can also easy to see the uptrend of clearance between the crankshaft and engine block with increasing operating temperature.

In order to the control of quality surfaces affected by wear, for comparison between simulated and the effective results on a test engine, it can use successfully a system of automatic control surfaces in combining with a coordinate measuring system mounted on a robotic arm with five degrees of freedom [11].

Conclusions

In the phase of cold-start under extreme low temperatures of any engine, in the first seconds after the starting process appear wears and in time defects that can affect the engine operation. The paper presents how the thermal contractions influence the crankshaft bearings under extreme low temperature for a V6 internal combustion engine. The thermal contraction phenomenon generates mechanical wear of rotating parts surfaces in the components of the engine. This research is focused on crankshaft bearings component, thermal contractions and thermal clearances are determined for different negatives temperatures, using F.E.A. method implemented in ANSYS software system. For thermal clearances the data were processed and mathematical models are determined. They can be used for calculating the thermal clearance at a specified negative temperature and for implementing in software tools.

The work is addressed to the specialists in the design and manufacturing of internal combustion engines and automotive maintenance specialists, by presenting the depth of the phenomena of generation of wear on cold start phase of engines.

The future research will focused on the thermal deformation analysis for the other components of the powertrain.

Acknowledgements

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References

[1] Haba S.A., Oancea G., Digital Manufacturing of Single-Cylinder Engine Block, The International Journal of Advanced Manufacturing Technology, Springer-Verlag London, DOI 10.1007/s00170-015-7038-x.(2015).

[2] Ghionea I. G., CATIA V5 Applications in mechanical engineering, Bren Publishing, Bucharest, Romania, 2009.

[3] Chareonsuk J., Vessakosol P., Numerical solution for functionally graded solids under thermal and mechanical loads using a high-order control volume finite element method, Applied Thermal Engineering, Volume 31, Issue 2-3, (2011), 213–227.

[4] Strycker M., Schueremans L., Paepegem W., Debruyne D., Measuring the thermal expansion coefficient of tubular steel specimens with digital image correlation techniques, Optics and Lasers in Engineering, Volume 48, Issue 10, (2010), 978–986.

[5] Dissemination of IT for the Promotion of Materials Science (DoITPoMS), University of Cambridge, Available at: http:// http://www.doitpoms.ac.uk.

[6] Dezső G., Varga G., Szigeti F., Investigation the correlation between technological parameters and the wear in case of drilling with minimal lubrication, Annals of Faculty Engineering Hunedoara – International Journal of Engineering, Tome IX/2, (2011), 97–100.

[7] Cozzens R., CATIA V5 Workbook Release V5 - 6R 2013, SDC Publications, 2013.

[8] ANSYS – Structural Analysis Software, Available at: http:// www.ansys.com. 2014.

[9] Jula A., Machinery parts course, Available at: http:// www.unitbv.ro.

[10] Haba S.A., Oancea G., Thermal Expansion Analysis of the Complex Body Assemblies, Applied Mechanics and Materials Vol. 309 (2013) 162–169.

[11] Tsagaris A., Efkolidis N., Stampoulis K., Kyratsis P., Reverse engineering techniques integrated into robotic system for surface reconstruction, Academic Journal of Manufacturing Engineering, Vol. 10, Issue 3 (2012), 113–118.